Physicochemical Properties of Calcium-Fortified Rice[1]

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ABSTRACT

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U.S. long-grain rough rice, Karen variety, was dehulled, milled, and graded. Milled rice was fortified with calcium by soaking in 3% calcium lactate (solution of rice and calcium lactate 1:0.75, w/v) for 3 hr at ambient temperature, followed by steaming at 10 psi for 10 min and drying to 10–11% moisture. The fortified milled rice and the untreated control contained 134 ± 2 mg of Ca/100 g of rice and 64 ± 3 mg of Ca/100 g of rice (dwb), respectively. Calcium-fortified uncooked and cooked rice showed significantly harder and firmer texture than did the untreated control. Furthermore, calcium-fortified rice and water-treated rice showed significant decreases in amylograph gelatinization temperature and peak viscosity. Sensory evaluation data indicated significant decreases in oral tenderness and adhesiveness values for calcium-fortified rice. Calcium-fortified milled rice may find several applications in rice-based food products.

Rice (*Oryza sativa* L.) is one of the leading food crops of the world, the staple food of over half the world's population (Juliano 1985). At least 90% of the world's rice farmers and consumers are in Asia, where rice provides up to 75% of the dietary energy and protein for 2.5 billion people (Juliano 1990). Good nutritional quality of rice is of primary interest to consumers all over the world. In the United States, consumer recognition of brown rice as a healthy food has shifted interest toward a greater consumption of brown rice (Marshall and Wadsworth 1994). Although milled rice is superior to brown rice in palatability and digestibility, the milling process results in fewer nutrients than in brown rice (Misaki and Yasumatsu 1985). Therefore, the enrichment and fortification of rice are of continued interest to consumers and food processors.

Calcium has been recognized as an important component in the body, constituting ~2% of the total weight, and ~99% of the calcium is present in the skeleton (Ranhotra 1986). The Recommended Dietary Allowance (RDA) of calcium for adults and pregnant and lactating women is 800 mg and 1,200 mg, respectively, per day (U.S. Food and Nutrition Board 1974). Calcium deficiency causes osteoporosis affecting ~24 million Americans annually (NIH 1991). With increasing concern over the nutritional value of our food products, use of nutritional supplements is on the increase and attitudes toward food fortification are changing. Niewoehner (1988) stated that increasing the intake of a variety of calcium-containing foods might be safer than calcium supplementation because the ingestion of large quantities of calcium concentrated in tablet form may suppress bone remodeling as well as bone resorption. The consumption of rice as food in the United States has doubled during the past decade (1980: 21 million cwt; 1990: 40.4 million cwt) (USDA 1992). Therefore, milled rice could be considered a suitable vehicle to fortify many American foods with calcium. The objectives of this study were to fortify milled rice with calcium, and to investigate the quality and physicochemical properties of calcium-fortified milled rice.

MATERIALS AND METHODS

Materials

U.S. long grain rough rice, Karen variety, was provided by the University of Arkansas, Rice Research and Extension Center, Stuttgart, AR. Calcium lactate (USP–FCC food grade, J. T. Baker Chemical Co., Phillipsburg, NJ) was used as the source of calcium in soak solution.

Preparation of Calcium-Fortified and Nonfortified Milled Head Rice

Rough rice (8 kg) was dehulled by using a testing husker (THU-35A, Satake Engineering Co., Tokyo). The hull was discarded and the brown rice was milled (No. 2 mill, McGill, Brookshire, TX) for 30 sec. Broken rice kernels were separated from the head rice using a test rice grader (TRG-05A, Satake).

Preliminary trials were conducted to optimize conditions that would allow maximum uptake of calcium into milled rice (Lee 1994). These conditions included: 1) calcium lactate concentrations of 0.5, 1, 2, or 3%; 2) rice-to-calcium lactate solution ratios of 1:0.5, 1:0.75, 1:1, 1:1.5, or 1:2.5; and 3) soaking times of 0.5, 1, 2, 3, 5, or 10 hr. Milled head rice (260 g) was soaked in water (rice and water, 1:0.75, w/v) for 3 hr. The soaked product was drained on a 18-mesh sieve for 5 min and spread <0.5 in. depth onto cheese cloth in a shallow stainless basket (9- × 11-in. size, containing 0.25-in. diameter holes at the bottom). The basket with rice was autoclaved in a retort at 10 psi for 10 min. The rice was removed and dried at 35°C to ~16% moisture, followed by drying at ambient temperature to ~11–12% moisture. The procedure, as described, was repeated for all treatments, except that 1.5 and 3.0% calcium lactate solutions were used instead of water.

Preparation of Calcium-Fortified and Nonfortified Rice Flour

Samples (120 g) of calcium-fortified and nonfortified milled rice were ground into flour using a sample mill with a 0.5-mm screen (Cyclotec 1093, Tecator, Hoganas, Sweden). The flour was sieved (Airjet Siever, Alpine, Augsburg, Germany) through a 60-mesh sieve.

Moisture Content

The percentage moisture content of rice flour was determined by an air oven method (AACC 1995).

Calcium Content

Calcium content was determined by the atomic absorption spectrophotometric method (AOAC 1990).

Color

The color of rice was measured using a colorimeter (Pacific Scientific Gardner Colorgard System 1000, Gardner/Neotec Instrument Division, Silver Spring, MD) calibrated with a white standard plate (L = 92.0; a = −1.5; b = 1.1) (Roberts et al 1954). L values indicate white (100) to black (0); a values indicate red (100) to green (−80); b values indicate yellow (70) to blue (−80).

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Translucency and Whiteness

The translucency and whiteness of grains were measured using a milling meter (MM-1B, Satake).

Grain Hardness

Hardness of 50 randomly selected head rice kernels was measured by using an Instron universal testing instrument with a 100-kg compression cell (Goodman and Rao 1985).

Firmness of Cooked Rice

Samples (40 g) of calcium-fortified and nonfortified head rice were rinsed three times with deionized water and placed in a 250-ml beaker. Deionized water (80 ml of rice and water, 1:2, w/v) was added to each sample. The beaker was covered with a watchglass, placed in a rice cooker (RC-100H, Toshiba Corp., Tokyo) containing 300 ml of deionized water, cooked for 20 min, and held for 10 min. Cooked rice was stirred with a plastic spoon and transferred into a plastic zipper bag to cool for 1 hr and to allow the moisture to equilibrate (Carroll 1988).

A texture test system (TP-1A, Food Technology Co., Reston, VA) with a 10-blade Kramer shear cell was used to measure the firmness of 100 g of cooked rice (Kohlwey 1994).

Water Absorption and Moisture Content of Cooked Rice

Rice (8 g) and deionized water (16 ml) were cooked as described for firmness measurement. The water absorption ratio was computed as the weight of cooked rice to the weight of uncooked rice (Carroll 1988). The percentage moisture content of cooked rice was determined as described above.

Amylographic Pasting Characteristics

The cooking quality of rice was evaluated using a Brabender Viscoamylograph 1725E. A 10% slurry was made from rice flour (40 g, dwb) and deionized water (300 ml) and homogenized by blending for 1 min. The contents were then transferred into a viscometer bowl. The blending bowl was rinsed with deionized water (60 ml), and the washing was added to make a total volume of 360 ml in the viscometer bowl.

The slurry in the viscometer bowl was equilibrated at 25°C, and the measuring device was adjusted to zero. After 5 min of equilibration, the slurry was heated to 95°C at 1.5°C/min and held for 30 min. This was followed by cooling at 1.5°C/min. to 50°C (AACC 1995).

The amylograms generated information about: gelatinization temperature, peak viscosity, breakdown viscosity, setback viscosity, and amylographic consistency, all in Brabender units (BU).

Sensory Evaluation

Rice samples stored in the refrigerator were removed within one month of receiving, cooked as described above, and transferred into a clean glass beaker.

A six-member sensory panel was trained over a six-day period to evaluate the texture of cooked rice samples (oral tenderness and oral adhesiveness attributes) using an unstructured 15-cm line scale. Oral tenderness is defined as the force required to deform rice kernels during the first bite of chewing. Oral adhesiveness is defined as the force required to separate molars after the second bite of chewing.

After the training, the panelists evaluated the test samples over a four-day period. There were four variations of milled rice (control, water-treated, and 1.5 and 3.0% [w/v] calcium lactate-treated). Each variation was evaluated five times in a randomized order, making a total of 20 samples for evaluation. Commercial long-grain milled rice was the reference, therefore, six 20-g samples (including reference) were evaluated every period. The samples were evaluated at ambient temperature, on white plastic plates. Lighting was provided by GE Chroma 50 lamps.

Statistical Analysis

Five replicates of each variable were performed and data were analyzed by analysis of variance. For physicochemical variables, the sources of variation were treatment. For sensory attributes, the sources of variation were day, panelist, day × panelist, and treatment. Mean separation of treatments was accomplished using the 5% level least significant difference (LSD) when the F-test for treatments was significant at the 5% level ($P < 0.05$).

RESULTS AND DISCUSSION

Calcium Content

Calcium content of calcium-fortified and nonfortified milled rice are given in Table I. Hoffpauer and Wright (1994) reported that 100 g of fortified rice may contain not less than 110 mg and not more than 220 mg of calcium. Soaking milled rice in 3% calcium lactate solution for 3 hr in a rice and calcium lactate solution (1:0.75, w/v) resulted in a maximum amount of calcium uptake of 134.4 ± 1.5 mg/100 g (dwb) of milled rice. The untreated control had calcium content of 63.6 ± 3.2 mg/100 g of rice. Calcium lactate was selected for fortification because of its nonmetallic and pleasant mouthfeel, as perceived by the investigators.

Rice samples fortified with calcium at 134.4 ± 1.5 mg/100 g (3.0% calcium lactate solution) or 105.3 ± 6.1 mg/100 g (1.5% calcium lactate solution) were investigated for physicochemical and sensory properties.

Color, Whiteness, and Translucency

Differences were observed in the color values, whiteness, and translucency of calcium-fortified and nonfortified milled rice ($P > 0.05$) (Table II). Calcium-treated samples did not differ from the control in their L values, while a values were lower and b values were higher than those of the control. However, whiteness of the calcium-treated samples did not differ from that of the control. Significant increases in the degree of translucency of both water-treated and calcium-fortified rice over that of the control were observed ($P < 0.05$) (Table II). Water-treated and calcium-fortified milled rice were more translucent than the control, which

TABLE I
Calcium Content of Calcium-Fortified and Nonfortified Milled Rice

Milled Rice Treatment[a]	Calcium Content[b] (mg/100 g)
Control (untreated)	63.6 c[c]
Incubation in water	54.7 c
Incubation in calcium-lactate (1.5%)	105.3 b
Incubation in calcium-lactate (3.0%)	134.4 a

[a] Incubation time 3 hr and autoclaved time 10 min.
[b] Means of 10 determinations on dry weight basis.
[c] Values in the same column with the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

TABLE II
Color, Whiteness, and Translucency of Calcium-Fortified and Nonfortified Milled Rice

Milled Rice Treatment[a]	Color[b] L	Color[b] a	Color[b] b	Whiteness[c] (%)	Translucency[c] (%)
Control (untreated)	72.1 b[d]	−0.3 a	16.2 c	31.2 b	2.57 b
Incubation in water	74.4 a	−2.4 d	18.5 a	32.5 a	3.99 a
Incubation in calcium-lactate (1.5%)	72.1 b	−0.9 b	17.2 b	31.2 b	3.69 a
Incubation in calcium-lactate (3.0%)	72.4 b	−1.8 c	17.3 b	31.5 b	3.84 a

[a] Incubation time 3 hr and autoclaved time 10 min.
[b] Means of 15 determinations. L = white (100) to black (0), a = red (100) to green (−80), and b = yellow (70) to blue (−80).
[c] Means of five determinations.
[d] Values in the same column with the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

might be due to gelatinized starch granules, disrupted air space, and protein bodies adhering to each other to form a compact mass, reducing light scattering at the boundaries of the granules. Calcium-fortified milled rice does not impart any undesirable color or exhibit higher translucency, which might give this product favorable acceptance by consumers.

Texture of Uncooked and Cooked Rice

The grain hardness (uncooked) and firmness (cooked) of calcium-fortified and nonfortified rice are given in Table III. The hardness of calcium-fortified and water-treated uncooked rice was significantly greater than that of the control ($P < 0.05$). Significant increases in the firmness values of calcium-fortified and water-treated cooked rice over that of the control rice samples were also observed ($P < 0.05$). An increase in calcium lactate concentration from 1.5 to 3.0% significantly decreased grain hardness (11.85 kg/kernel vs. 11.08 kg/kernel) ($P < 0.05$), possibly due to pregelatinization of starch during fortification process. However, this effect was not linear. No such difference due to level of calcium fortification was observed in firmness of cooked rice. Retrogradation and cross-linking are two starch modification methods that alter the physical and chemical properties of starch. Calcium-fortified uncooked showed harder texture and cooked rice showed firmer texture when compared to the control. This may be caused by entrapment of Ca^{++} and formation of complexes with linear amylose polymers, and the retrogradation of pregelatinized starch during the fortification process. Sharp and Sharp (1994) stated that retrogradation of the rice starch promotes the development of a firmer kernel surface, maintaining a greater degree of kernel integrity and individuality.

TABLE III
Uncooked Grain Hardness and Cooked Grain Firmness of Calcium-Fortified and Nonfortified Milled Rice

Milled Rice Treatment[a]	Grain Hardness[b] (kg/kernel)	Firmness[c] (kg/100 g)
Control (untreated)	7.9 d[d]	57.1 c
Incubation in water	10.2 c	59.4 b
Incubation in calcium-lactate (1.5%)	11.8 a	62.0 a
Incubation in calcium-lactate (3.0%)	11.1 b	61.3 a

[a] Incubation time 3 hr and autoclaved time 10 min.
[b] Means of 50 determinations.
[c] Means of five determinations.
[d] Values in the same column with the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

TABLE IV
Moisture Content and Hydration of Calcium-Fortified and Nonfortified Cooked Milled Rice

Milled Rice Treatment[a]	Moisture Content of Cooked Rice[b] (%)	Hydration Ratio[c]
Control (untreated)	71.1 b	2.09 c[d]
Incubation in water	72.8 a	2.16 b
Incubation in calcium-lactate (1.5%)	72.4 a	2.19 ab
Incubation in calcium-lactate (3.0%)	73.1 a	2.26 a

[a] Incubation time 3 hr and autoclaved time 10 min.
[b] Means of six determinations.
[c] Means of three determinations.
[d] Values in the same column with the same letter or letters are not significantly different ($P < 0.05$) by Duncan's multiple range test.

Moisture Content of Cooked Rice and Hydration

Moisture content and hydration ratio of calcium-fortified and nonfortified cooked rice are given in Table IV. The moisture content of calcium-fortified and water-treated cooked rice was significantly higher than that of the control ($P < 0.05$). Inorganic salts can either increase or decrease the water uptake during cooking. It was also reported that adding calcium chloride decreases the loss of grain material during cooking (Ghosh and Sarkar 1959). In the present study, cooking calcium-fortified rice in excess water maintained a better kernel integrity compared to that of the control samples and had minimal leaching out of starch components. Significant increases in the hydration ratio of calcium-fortified cooked rice and the control were also observed ($P < 0.05$). Moisture content of cooked rice and hydration were not affected by the level of calcium fortification. These values show the ease of hydrating calcium-fortified rice. Juliano et al (1965) reported that cooking time is related to water absorption. A faster rate of water uptake indicates a shorter cooking time. Calcium-fortified rice is precooked and gelatinized in steam and dried to retain the rice grains in a porous and open structured condition. Hence, it is easily hydrated and the cooking time should be shorter.

Amylographic Pasting Characteristics of Rice Flour

Amylographic pasting characteristics of calcium-fortified and nonfortified milled rice are given in Table V. Calcium-fortified and water-treated rice flour showed significant decreases in gelatinization temperature, peak viscosity, breakdown viscosity, and consistency; and an increase in setback viscosity ($P < 0.05$). None of these attributes were affected by the level of calcium fortification (Table V). Paste consistency and changes in the gel and viscosity properties during the pasting cycle influence the product quality and can be of special interest to food product manufacturers. Lower gelatinization temperature and lower peak viscosity for calcium-fortified rice compared to that of the control might favorably contribute to the further processing of rice into products and result in net savings of time and energy.

Soaking and steaming involved in calcium fortification process might pregelatinize the starch component and thus contribute to the ease of cooking. Breakdown viscosity is a measure of the susceptibility of cooked starch to disintegration (Rasper 1980). Lower breakdown viscosity of calcium-fortified rice indicated the ease of cooking. It is probable that cross-bonding reduced the ability of the starch to swell and thus prevented the increase in viscosity that would have occurred due to the breakdown of highly swollen granules. Therefore, calcium fortification might enhance the stability of the hot paste.

Setback viscosity and amylographic consistency measure the degree of hardening or retrogradation of cooked rice during cooling. Retrogradation is the recrystallization or reassociation of gelatinized starch; it is normally used to indicate the thickening phenomenon that occurs during the cooling of cooked starch

TABLE V
Amylographic Pasting Characteristics of Calcium-Fortified and Nonfortified Milled Rice Flour[a]

Milled Rice Flour Treatment[b]	Gelatinization (°C)	Peak Viscosity (BU)	Breakdown Viscosity (BU)	Setback Viscosity (BU)	Consistency (BU)
Control (untreated)	50.4 a[c]	795 a	330 a	108 c	438 a
Incubation in water	33.9 b	485 b	81 b	202 b	282 b
Incubation in calcium-lactate (1.5%)	34.2 b	428 c	17 c	273 a	290 b
Incubation in calcium-lactate (3.0%)	34.6 b	424 c	12 c	268 a	281 b

[a] Means of three determinations.
[b] Incubation time 3 hr and autoclaved time 10 min.
[c] Values in the same column with the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

TABLE VI
Sensory Evaluation of Calcium-Fortified and Nonfortified Cooked Milled Rice

Milled Rice Treatment[a]	Oral Tenderness[b] (cm/15 cm)	Oral Adhesiveness[c] (cm/15 cm)
Control (untreated)	7.26 c[d]	7.15 c
Incubation in water	8.81 b	8.06 b
Incubation in calcium-lactate (1.5%)	9.78 a	9.40 a
Incubation in calcium-lactate (3.0%)	9.92 a	9.32 a

[a] Incubation time 3 hr and autoclaved time 10 min.
[b] Means of 30 determinations. On 0 (tender) — 15 (firm) cm scale.
[c] Means of 30 determinations. On 0 (sticky) — 15 (well-separated) cm scale.
[d] Values in the same column with the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

(Sharp and Sharp 1994). Cross-linking of starch or starch-protein could have contributed to higher setback viscosity in the calcium-fortified rice (3.0% calcium lactate [268 BU] and 1.5% calcium lactate [273 BU]) than in the control (108 BU). The tendency to retrograde could be demonstrated by the amylographic consistency, the lower consistency indicating a better stability of the cold paste in a harder gel form.

Sensory Evaluation

Data for grain hardness, firmness of cooked rice, amylographic setback viscosity, and oral tenderness from sensory evaluation indicated that calcium-fortified rice samples have a harder uncooked and firmer cooked texture than that of the control. Sensory characteristics of calcium-fortified and nonfortified cooked milled rice are given in Table VI. Sensory data showed significant decreases in oral tenderness and adhesiveness of calcium-fortified and water-treated cooked rice over that of the control and in calcium-fortified cooked rice over that of the water-treated cooked rice ($P < 0.05$). Significant correlation was also found between oral tenderness and adhesiveness ($r = 0.85$) ($P < 0.05$). It is possible that Ca^{++} interacted with the surface components in rice and contributed to nonstickiness. Research is in progress to investigate this mechanism. Since American consumers prefer firm, dry, and fluffy cooked rice, the calcium-fortified rice would meet their rice preference and thereby enhance the marketing potential for milled rice.

CONCLUSION

A simple procedure has been developed to fortify milled rice with calcium. During cooking in excess water, we also observed that kernel integrity of calcium-fortified cooked rice was well maintained and that the contents from granules were not leached out into the cooking media. Calcium-starch complexing may play a positive role in the retention of water during high-temperature cooking and, hence, it may be considered suitable for canned food. In addition, calcium-fortified rice has a harder texture that could be of use in canned rice products. Calcium-fortified rice flour showed significant decreases in amylograph gelatinization temperature and peak viscosity, which can promote the processing of rice into products such as quick-cooking rice. The cooked calcium-fortified rice samples were fluffy and less sticky.

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